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Mr. *Winthrop's*

TWO

LECTURES

ON

COMETS.

BRITISH MUSEUM

TWO
LECTURES
ON
COMETS;

Read in the Chapel of *HARVARD-COLLEGE*, in CAMBRIDGE, NEW-ENGLAND, in *April* 1759.

On Occaſion of the COMET which appear'd in that Month.

With an APPENDIX, concerning the Revolutions of that Comet, and of ſome others.

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BRITISH MUSEUM

On COMETS.

LECTURE I.

THE appearance of the COMET, with which our heaven is now adorned, has induced me to quit at preſent the ſubject we were conſidering in the courſe of theſe Lectures, in order to lay before you ſome account of this extraordinary ſort of Bodies, which in all ages have commanded the attention of mankind. In treating which ſubject, I ſhall firſt briefly examin the principal hypotheſes that have prevail'd concerning Comets, and then explain more largely the true theory of them, according to the lateſt diſcoveries.

EVERY one knows that there are two ſorts of ſtars commonly to be ſeen in the heavens; ſome, movable; others, immovable. The immovable ones, generally call'd *fix'd* ſtars, have this title on account of their retaining invariably the ſame diſtances from, and poſitions towards each other. The movable ones are call'd *Planets*, from the greek word ΠΛΑΝΗΤΗΣ, which ſignifies a *wandering* ſtar; becauſe they are perpetually changing their places with regard to the fix'd ſtars, and to one another. Both of them ſhine, when the air is clear, with a briſk and vivid light. The *Comets* are a third ſort of ſtars; movable like the Planets, but greatly differing in ſeveral particulars from them, as well as from the fix'd ſtars. The Bodies of them uſually appear different from all the other ſtars; being of a dull and duſky light, like that of a ſtar ſhining thro' a thin cloud. They are incompaſſed with an hazineſs, call'd their *atmoſphere*, which generally appears much larger than the body, or, as it is otherwiſe call'd, the *nucleus* or *head* of the Comet. But what moſt remarkably diſtinguiſhes them from the reſt of the ſtars is their *tail*, which is a train of pale light, extended from their atmoſphere, ſometimes to very great lengths. From an imagin'd reſemblance of this to *hair*, a ſtar of this ſort was term'd in greek ΚΟΜΗΤΗΣ, that is, an *hairy* ſtar; which was the original of our word *Comet*. The matter of which this tail conſiſts is ſo extremely rare, that the ſmalleſt ſtars appear thro' it without any diminution of their luſtre. When the tail is of a conſiderable length, it has a ſenſible curvature, convex on that ſide to which the Comet is moving; but if it be ſhort, this curvature is ſcarcely perceived. It is generally broader towards the end than near the head of the Comet, and of a fainter light; and it's direction is oppoſite to the ſun;--- not exactly ſo indeed, but deviating a little that way from which the Comet has mov'd. Sometimes it is bifurcated, like two branches proceding from one ſtem. It ſometimes appears to go before the head of the Comet, and ſometimes to follow it; and ſometimes to ſurround it on all ſides. The apparent courſes of Comets alſo differ very much from the planetary ones. The Planets never depart far from the ecliptic; whereas Comets range thro' all parts of the heavens. And as they make their firſt appearance indifferently in any conſtellation, tho' moſt commonly within 90° of the Sun, or in ſome part of that hemiſphere which has the Sun in the middle of it; ſo they move indifferently any way, either from ſouth to north, or from north to ſouth; and ſometimes are ſeen to run off even to the very poles. In one particular indeed, their motions agree with thoſe of the planets. For as the planets are ſometimes ſeen to procede with a *direct* motion, or from weſt to eaſt, and then, in other aſpects with the Sun, to be *retrograde*, or go backwards from eaſt to weſt; ſo have ſeveral Comets, whoſe motion was at firſt direct, become afterwards retrograde; and others have alter'd their courſe from retrograde to direct. Comets are not always to be ſeen, as the planets are; but only occaſionally, and after uncertain intervals of time. Sometimes ſeveral have been diſcover'd within the compaſs of a few years; but for the moſt part, their appearances have not been ſo frequent. They are ſeen but a little while, only for a few weeks, or months at moſt; and tho' when they firſt ſhew themſelves, ſome of them are bright and large, equal in apparent diameter to Jupiter and Venus, and almoſt the * moon itſelf; yet they are commonly obſerv'd to diminiſh in magnitude, in brightneſs and in the length of their tail, until they become quite inviſible. Such are the general phænomena of Comets; and theſe the teſts, by which every hypotheſis concerning them is to be tried.

A variety of opinions hath been entertained, as to the nature and place of theſe bodies. Some have look'd upon them to be worlds on fire †; and ſome, nothing more than lucid meteors: And while many have confined them within the narrow limits of our atmoſphere, others have raiſed them up to the fix'd ſtars. So widely do men differ, when, inſtead of ſearching into the nature of things, they indulge their own imaginations.

It was an antient doctrine of ſome *Pythagorean* philoſophers, ‡, that the Comets are a peculiar kind of wandering ſtars; that they are to be reckoned among the permanent bodies of the univerſe; that they move in their proper orbits, completing their courſes in ſtated times: But that they are viſible only in a ſmall part of their orbits, and return not again till after a long period of years; being too remote, during the greateſt part of their revolution, to be diſcern'd by us. But the *Peripatetic* ſcheme afterward prevailing, the philoſophers of that ſect, who held that the heavens are abſolutely immutable and incapable of generations and corruptions, regarded the Comets, not as ſtanding works of nature, but as new productions which quickly periſh; and maintain'd them to be only a kind of meteors formed out of the exhalations of our atmoſphere, and much below the moon; being apprehenſive that, if they were placed higher, their appearing and diſappearing ſo uncertainly would diveſt the heavenly region of that privilege of immutability which they had aſſigned it. In this they were confirm'd by another notion they had taken up, that the planets were carried round in their courſes by ſolid cryſtal orbs; thro' which, to be ſure, the Comets could not penetrate. Thus does one error lead to another. And by the way, the prevalence of this opinion has had an ill effect, and has been the true reaſon why this moſt curious part of aſtronomy, which relates to Comets, lay uncultivated for ſo many ages; the philoſophers, who had imbibed ſuch notions, thinking it to no purpoſe to deſcribe with accuracy the irregular motions of ſuch vaniſhing vapors. Had the antients obſerv'd the paths of Comets among the fix'd ſtars with the ſame care as they did thoſe of the Planets, the aſtronomy of Comets had, in all probability, by this time been brought to almoſt the ſame perfection with that of the Planets. But as the opinion, that the Comets were meteors and below the moon, obtain'd for many ages almoſt univerſally, and was the only one publicly taught till the time of TYCHO BRAHE, an eminent aſtronomer of the ſixteenth century, it has hence come to paſs, that we have nothing certain tranſmitted to us, of the motion of any Comet, till within theſe laſt 200 years; thoſe which appeared before, having not been deſcribed by aſtronomers, but only mention'd by hiſtorians as prodigies, or omens of dreadful calamities. But TYCHO, having carefully obſerv'd a remarkable Comet, found by repeated trials, that it was not ſubject to a diurnal parallax; for it appear'd at the ſame time in the ſame place among the fix'd ſtars, to two obſervers at the diſtance of ſeveral hundred miles from each other. This obſervation at once overthrew the doctrine of the ſchools, and placed the Comet far above the moon. The aſtronomers, who came after TYCHO, having diligently watch'd the Comets which appear'd in their days, have found that the diurnal parallax of all of them is either wholly imperceptible, or extremely ſmall;---a demonſtration, that Comets cannot be aereal meteors, but ought to be rank'd amongſt the heavenly bodies. Indeed, their partaking of the apparent diurnal motion of the heavens might have taught thoſe philoſophers better, and was a ſufficient indication that Comets are not appendages of the earth.

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* As the Comet of 1652. HeveliiCometogr. Lib.VI. p. 326.

† Which ſeems to be the idea convey'd by our vulgar term *Blazing ſtars.*

‡ Gregorii Aſtron. Lib. V. Sect. i.

As the want or ſmallneſs of a diurnal parallax has raiſed Comets above the moon, ſo from their being ſubject to an annual parallax it is certain that they are not among the fix'd ſtars, but deſcend into the region of the planets. Tho' they are at too great a diſtance to have their apparent place alter'd by being view'd from different parts of the earth, yet they come near enough to have it alter'd by being view'd from different parts of our annual orbit. Accordingly, their apparent motion is ſenſibly affected by the annual motion of the earth, in the ſame manner as that of the planets is. The real motion of all the planets round the ſun is conſtantly direct, or from weſt to eaſt; and not very unequal in the ſeveral parts of their orbits; and would appear to be ſo, if viewed from the ſun, which is fix'd in the centre of their orbits; but their apparent motion, as view'd from the earth, which moves the ſame way as they do, is very various. Sometimes they are ſeen to go ſwifter, ſometimes ſlower, with a direct motion; then to be retrograde, going the contrary way, or from eaſt to weſt; and between theſe oppoſite motions, they appear for a little while ſtationary, or without any motion at all. Theſe appearances depend on the motion of the earth, as that happens to conſpire with, or be contrary to, and to be ſwifter or ſlower than, the real motion of the planets. And for the ſame reaſon muſt the apparent motion of Comets be changed, if they move within the planetary orbs. Thoſe, whoſe real motion is direct, will appear ſtationary and retrograde, or at leaſt much ſlower, in nearly the ſame aſpects with the Sun, as the Planets appear ſo; but thoſe, whoſe real motion is retrograde (for ſuch is the motion of ſome Comets) will, in the ſame aſpects, appear ſtationary and direct. And converſly, ſince this is the caſe in fact*;--ſince the viſible motion of Comets is alter'd, as the earth's annual motion would require on the ſuppoſition of their coming into the region of the Planets, it follows, that they do come into the region of the Planets. Thus, by the way, the Comets ſupply us with a new proof, that the earth revolves round the Sun; for without ſuppoſing this revolution, their motions cannot be reduc'd to any ſort of regularity. So far indeed are Comets from being among the fix'd ſtars, that it appears from their annual parallax, that they are ſeldom ſeen till they come within the orb of Jupiter †, and that they frequently deſcend below the orbs of Mars and the inferior planets.

SOME aſtronomers, who had rightly placed Comets in the region of the Planets, have been miſtaken in their thoughts on the conſtitution of theſe bodies. It has been ſuppoſed, that Comets were formed by the coalition of ſome ſubtle exhalations from the Planets; and that they were, with regard to the Sun, of the ſame nature as what are called *ſhooting ſtars*, with regard to the earth. But this opinion is overthrown by what Sir ISAAC NEWTON has obſerv'd * of the remarkable Comet which appear'd in the year 1680. The earth is above 160 times farther from the Sun, than that Comet was in it's perihelion. Now the heat of the Sun, being as the denſity of the rays, is in every place reciprocally as the ſquare of the diſtance of that place from the Sun; and therefore the heat of the Sun at the Comet in it's perihelion was above 26000 times greater than it is at the earth. But the heat of boiling water is about three times as great as that which dry earth contracts from the ſummer-ſun; and ſo the heat at the Comet was about 9000 times greater than that of boiling water. And the heat of red-hot iron Sir ISAAC conjectures to be about three or four times greater than that of boiling water; wherefore the heat, which dry earth on the Comet in it's perihelion might contract from the rays of the Sun, was about 2000 times greater than that of red-hot iron. But by ſo intenſe an heat as this, all volatile matter muſt preſently have been conſumed and diſſipated; and the Comet, which could endure this moſt violent heat, certainly did not conſiſt of vapors or exhalations of any kind.

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* See before, p. 7.

† Newtoni Principia, p. 480.

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* Princip. p. 508.

DIFFERENT conjectures have been propoſed to account for that peculiar phænomenon of Comets, their *tails*. That theſe depend in ſome manner on the Sun, is plain from their perpetually pointing to the part oppoſite to the Sun; as hath been obſerv'd of all the Comets within theſe laſt 200 years. This, in the general, the later aſtronomers have agreed in; but have differ'd in explaining the particular manner in which the Sun produces ſuch an appearance. Some have thought the tails of Comets to be nothing but the rays of the Sun tranſmitted thro' the body or head of the Comet, which for this purpoſe they are obliged to ſuppoſe tranſparent; and ſo yielding the appearance of a ſun-beam *behind* the Comet, that is, on the ſide oppoſite to the Sun. And others have added, that the rays are refracted in paſſing thro' the head, as thro' a glaſs lens. This they illuſtrate by the example of the Sun's ſhining thro' a ſmall hole into a darken'd room, in which caſe a ſtream of light is ſeen extended from the hole. But this hypotheſis will by no means account for the phænomenon in queſtion. It might be urged againſt it, that the tranſparence of the Comet is an arbitrary ſuppoſition; and that for the moſt part, the figure does not anſwer; ſuch a ſtream of light in a darken'd room being always perfectly ſtrait, whereas the tails of Comets are often curved: Neither does the direction anſwer; ſuch a ſtream of light being always exactly oppoſite to the Sun, whereas the tails of Comets uſually deflect a little from the preciſe point of oppoſition. But not to inſiſt upon theſe arguments, it ſhould be conſidered, that a Sun-beam in a darken'd room is perceiv'd, only ſo far as the light is reflected from the particles of duſt and ſmoke, which are always floating in the air. For the rays of light in the beam are not diſcerned by an eye placed on the ſide of it, any otherwiſe than by being reflected to the eye from ſome ſubſtance in the place where the beam appears. And hence it is, that when the air is full of thick ſmoke and duſt, ſuch a ſun-beam appears brighter; for there being then a greater number of reflecting particles, a greater number of rays are reflected, and ſtrike the eye more ſtrongly. When the air is more clear and free from motes, the ſun-beam appears fainter, and is not ſo eaſily perceiv'd; and if there were no reflecting matter there at all, it could not at all be perceived. Since therefore viſion is cauſed only by thoſe rays which fall on the eye, it is neceſſary to ſuppoſe ſome reflecting matter where the tail appears; and this matter muſt be groſſer and denſer in that place than in the other æthereal regions; otherwiſe, the whole heaven, being equally illuminated by the Sun, would ſhine as much as the tail of the Comet, and appear throughout of an uniform brightneſs. The tail therefore does not procede from the rays of the Sun tranſmitted through the head of the Comet.

A LATE Author has attempted to mend this hypotheſis, by ſuppoſing that the rays of the Sun are refracted in paſſing thro' the atmoſphere of the Comet, and ſo made to converge on the part oppoſite to the Sun; and the light being by this means condenſed, illuminates that part of the atmoſphere, enough to render it viſible to us; and that this illuminated part is what is called the Comet's *tail.* But beſides that this opinion is liable to almoſt the ſame difficulties as the foregoing, it ſuppoſes the atmoſphere of a Comet to be extended all round the body, tho' inviſibly, to the ſame diſtance as the tail is, which in ſome caſes has been many millions of miles;---a ſuppoſition, which, without ſome further proof, will not eaſily gain belief.

OTHERS, who ſaw the inſufficiency of the foregoing hypotheſis of the tranſmiſſion of light, have advanced another, ſtill more improbable, and endeavour'd to account for the tails of Comets by the refraction of light in it's paſſage from the head of the Comet to the earth. They have ſuppoſed that as the round image of the Sun, by being refracted in paſſing thro' a glaſs priſm, is thrown into an oblong form; ſo the light proceding from the round head of the Comet may, in paſſing thro' the æthereal regions, be refracted in ſuch a manner as to appear long, and produce this phænomenon of the tail. To this opinion it is an obvious objection, that the rays of the fix'd ſtars and planets, ſince they paſs thro' the ſame medium as thoſe which come from Comets, are liable to the ſame refraction, and ought therefore to exhibit the ſame appearance; and ſome of theſe ſhould have larger and brighter tails than moſt Comets, ſince their light is much ſtronger. But even thoſe ſtars and planets, whoſe light is ſtrongeſt and moſt copious, have no tails; nor can any be diſcover'd belonging to them by the beſt teleſcopes, which will increaſe their light above 100 times; while ſome Comets, whoſe light was but weak and dull, have had very large and bright tails. Beſides, the tails of Comets are never variegated with colors, as the oblong image produced by the priſm is; which variety of colors is a neceſſary reſult of that unequal refrangibility of the rays, by which the priſmatic image, inſtead of being round, is made oblong. Farther: If the tail aroſe from the refraction of light in it's paſſage thro' the heavens; whenever the light paſſes thro' the ſame part of the heavens; it ought to be refracted the ſame way. But this is contrary to obſervation. For two Comets have been ſeen in the ſame place of the heavens, when the earth was likewiſe in the ſame part of it's orbit; yet their tails have not been turned the ſame way, but have contain'd a large angle between them *. This difference in their direction could not be the effect of a refraction in the

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* A remarkable inſtance of this may be ſeen in Newt. Princip. p. 510, 511.

heavens, which in ſuch circumſtances muſt have been the ſame. Theſe cauſes therefore being rejected, the phænomena of the tails muſt be derived from ſome matter in them, which reflects light.

The aſcent of the tails towards the parts oppoſite to the Sun, ſome authors of note have aſcribed to the action of the Sun's rays, driving the matter of the tail before them. And conſidering the extreme rarity of the vapor which compoſes the tail, and the ſurpriſing velocity of the rays of light, perhaps it may not be altogether impoſſible for the matter of the tail to yield in ſome meaſure to the impulſe of the rays, and be driven before them that way towards which their motion is directed; that is, to the parts oppoſite to the Sun. But if ſuch a cauſe ſhould be allowed to have ſome ſmall ſhare in producing the phænomenon, yet this can hardly be deem'd an adequate ſolution; nor ſhould much ſtreſs be laid upon it,as we know of no parallel inſtance in nature to ſupport it.

As to the line in which Comets move,ſome of the moſt conſiderable aſtronomers of the laſt century ſuppos'd it to be a ſtrait line, or nearly ſo. Kepler, from his own obſervations of two Comets, concluded that they moved freely any way between the orbits of the Planets, with a motion not very different from a rectilinear one. Hevelius, who carefully obſerv'd ſeveral Comets, imbraced the ſame hypotheſis; but was ſenſible that his calculations founded upon it did not perfectly agree with the heavens, and perceived that the path of a Comet was in a line incurvated towards the Sun. But what this curve is, theſe aſtronomers, like all who went before them, were unable to determine.

WE have now ſet aſide ſome of the falſe opinions concerning Comets, which have been moſt regarded. It has been ſhew'd that they are neither below the moon, nor among the fix'd ſtars; that they conſiſt not of any kind of exhalations;---that their tails are not produced by the tranſmiſſion of light thro' their bodies; nor by any refraction of light, cauſed either by their atmoſpheres or by the celeſtial matter thro' which it paſſes;---that the tails are not turned oppoſite to the Sun by the impulſe of his rays; and laſtly, that the motion of Comets is not in ſtrait lines. Some better account of theſe things is therefore to be ſought for.

INDEED, the opinions concerning Comets, which formerly paſs'd current with many, were ſuſpected by others. Thus, SENECA the philoſopher, diſſatisfied with the doctrine of his time relating to them, and unable to ſubſtitute a better, foretold, that "in future ages, ſome "man would demonſtrate in what parts of "the heavens the Comets wander, why they "depart ſo far from the other wandering ſtars, "and what ſort of bodies they are*." The prediction has been fulfill'd in the preſent age; and this man was Sir ISAAC NEWTON. After many centuries elapſed, with little inſight gain'd into the true conſtitution of theſe bodies, and none at all into their real motions, this great genius aroſe, and with a ſtrength of mind peculiar to himſelf (I had almoſt ſaid, more than human)

> "Perſu'd the Comets where they fartheſt run,
> "And brought them back obſequious, to the Sun,"†

as POPE has happily expreſſed it. Form'd to penetrate into the moſt abſtruſe receſſes of nature, he traced theſe unknown travellers thro' every ſtep of their long journey, delineated the particular tour they make, and ſhewed by what ſecret influence they are determin'd to reviſit our planetary regions, after an abſence of ſcores, or rather centuries of years. The explication of theſe particulars you may expect in the next diſcourſe.

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* SENECA Natural. Quæſt. Lib. VII. Cap. xxvi.

Read, 11th of APRIL, 1759.

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LECTURE II.

IN the laſt diſcourſe we examin'd ſuch of thoſe falſe hypotheſes concerning Comets, as had been moſt regarded in the world. I then took no notice of ſome others which have been advanced upon this head, becauſe, as they carried leſs ſhew of probability, they have had fewer and leſs conſiderable advocates, and in conſequence have fallen into neglect. And for the ſame reaſon, I ſhall not ſpend any of the time allotted for the preſent exerciſe in the confutation of ſuch hypotheſes, but enter immediately upon the explanation of the true theory of Comets, for which the world is indebted to the unparallel'd invention of Sir ISAAC NEWTON. And here we ſhall begin with ſhewing what their real courſe in the heavens is, as that will throw light upon ſome other parts of their theory.

AN eſſential part of Sir ISAAC's doctrine is, that antient *Pythagorean* one already mention'd,*

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* In p. 8.

viz. that Comets are a kind of wandering ſtars, which are mov'd in peculiar orbits of their own. This doctrine received hardly any improvement untill his time, but he alone carried it to an hight, which might rather have been wiſh'd for than expected; and has left thoſe who come after him little to do, but to apply his theory to the ſeveral Comets, as they ſhall appear. According to this excellent Philoſopher then, The Comets are a kind of Planets, that is, firm, compact, durable bodies; revolving round the ſun in conic ſections, and, by right lines drawn to the ſun, deſcribing areas proportional to the times. That they are not formed of exhalations or vapors, but are firm, durable bodies, was ſhewed the laſt time; as alſo, that the aſtronomers before NEWTON, who ſuppoſed their trajectories to be nearly rectilinear, perceived they were not accurately ſo, but were rather bent in towards the ſun; tho' what the particular line of this motion was, they were not able to determine. But Sir ISAAC NEWTON has demonſtrated from his principle of *gravity*, that it muſt be ſome one of the conic ſections. For, having diſcover'd that all the globes in our ſyſtem mutually gravitate towards each other with forces reciprocally proportional to the ſquares of their diſtances; and that by this gravitation of the primary Planets to the Sun, they are reſtrained from going on in right lines, and are compell'd to move in curvilinear orbits; he next demonſtrated *, that whenever a body is made to revolve round another, by ſuch a centripetal force as this,---by a force which at all diſtances from the central body is reciprocally as the ſquares of the diſtances, the revolving body muſt neceſſarily deſcribe ſome conic ſection, in one focus of which the central body will be placed. And the ſpecies of the orbit will depend on theſe two circumſtances;---on the proportion which the velocity or projectile force of the revolving body bears to the force of its gravitation towards the central one; and on the angle contained between the directions of theſe two forces. The Planets therefore, whoſe motions are governed by ſuch a gravitating force, will move in ſome conic ſection. Accordingly, what KEPLER diſcovered is now eſtabliſhed by the general conſent of Aſtronomers, that the orbits of all the primary planets are one ſort of conic ſections, viz. ellipſes, in one focus of which the ſun reſides. This law is general, and extends to the ſecondary planets alſo; and the moon moves in an elliptic orbit which has the earth in one focus. And each of theſe planets, primary and ſecondary, by ſtrait lines drawn to the central body, deſcribes areas proportional to the times; and ſo moves ſwifter, as it comes nearer the centre: Which law of their motion Sir ISAAC NEWTON has demonſtrated to take place in all bodies revolving by any kind of centripetal force whatſoever.

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* Princip. Lib. I. Prop. xvii.

THESE points being ſettled, and Sir ISAAC, finding, as has been mention'd *, that the Comets come

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* See above p. 12.

come within the planetary regions, and conſequently within the reach of gravitation to the Sun, concludes, by force of the foremention'd demonſtration, that they,as well as thePlanets, muſt move in ſome conic ſection about the ſun. But there is no neceſſity that their orbits ſhould be of the ſame ſpecies as thoſe of the planets. The elliptic orbits of the Planets are all different, and the orbits of the Comets may be different from any of them. The conic ſections are three, viz. the hyperbola,parabola, and ellipſis; to which may beadded, the circle. The two former of theſe are extended infinitely; the latter return into themſelves. If the velocity of a Comet, at any diſtance from the ſun, were in the ſame proportion to the velocity of a Planet revolving in a circle at that diſtance, as the diagonal of a ſquare is to it's ſide, that is, nearly as 7 to 5, the Comet would move in a parabola *; and with a greater velocity, in an hyperbola: And in both theſe caſes, having once paſs'd by the Sun, it would never return more; the velocity acquired in it's deſcent being now great enough to throw it off to the fix'd ſtars, ſo that it's gravitation to the ſun would never be able to bring it back. With a leſs velocity than this, a Comet would move in an ellipſis; or, with a certain adjuſtment of the circumſtances, in a circle. If Comets be ſuppoſed to move in a parabola or hyperbola, their number muſt be vaſtly great, becauſe the number of their appearances hath been

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* Newt. Princip. Lib. I. Prop. xvi. Corol. 7.

hath been ſo; and each appearance muſt have been of a different Comet, ſince, on this ſuppoſition, no Comet could be ſeen twice. Beſides: We have no reaſon to think, that any of the bodies, which belong to our ſyſtem, can belong alſo to any ſyſtem among the fix'd ſtars; which ſeem to be placed at ſuch immenſe diſtances from us, with deſign to cut off all intercourſe between them and us. Farther: 'Tis certain that Comets do not revolve in circles, or in ellipſes of a ſmall eccentricity, as the Planets do; for if they did, they would be ſeen conſtantly, as the Planets are. But it is well known, that Comets are viſible but a little while *, and continue inviſible for a long time. It remains therefore, that they move in elliptic orbits of very great eccentricity; that is, whoſe length is very great in proportion to their breadth. But that ſmall part of ſuch an orbit, near the perihelion, which is all that can come under our obſervation, will almoſt coincide with a parabola; and may therefore, without any ſenſible error, be taken for one.

HERE our author had occaſion to exert his great abilities in ſolving a problem, the extreme difficulty of which render'd it worthy of his genius, and indeed inſuperable by any other. From three ſelect obſervations of the place of a Comet, ſuppoſed to move in a parabola, he has taught a method of delineating it's trajectory geometrically †; and has given an example of this ſolution in determining the tra-

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* p. 8.

† Newt. Princip. Lib. III. Prop. xli.

jectory of that famous Comet which he himſelf obſerved in the year 1680. He made it certain that the Comet really moved in the trajectory he had delineated, by computing it's places therein for the times of ſeveral obſervations; which agreed with it's places as they were actually obſerved at thoſe times *.

THIS excellent diſcovery has ſince been abundantly confirmed by the labors of the learned Dr. HALLEY, who, following the ſteps of Sir ISAAC NEWTON, has performed the ſame thing arithmetically, which that great man had done geometrically, and has expreſſed the orbits and motions of Comets by numbers. And having in this manner ſettled the orbits of all which had been well obſerved before the preſent century, to the number of 25, he found that their places computed in theſe orbits agreed as well with their obſerv'd places, as the computed places of the planets uſually agree with their obſerved places. The like computations having been ſince made by other aſtronomers for the Comets which have been ſeen in this century, the theory is conſtantly found to anſwer the obſervations. In this manner have the orbits of about 40 Comets been ſettled.

ALL theſe calculations have been made on the ſuppoſition, that the viſible part of a Comet's

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* Jam patet horrificis quæ ſit via flexa cometis;
Jam non miramur barbati phænomena aſtri. As Dr. *Halley* ſings on this occaſion.

met's trajectory is ſo nearly parabolic, that it may ſafely be taken for ſuch; tho' the whole orbit be really an ellipſis of very great eccentricity. Now the true ſpecies of an ellipſis ſo eccentric as the orbit of a Comet muſt be, cannot be determin'd with any exactneſs from ſuch a ſmall part of it as a Comet deſcribes, while it continues viſible: It can be determin'd no other way than from the periodical time of the Comet; and the periodical time will be known, by remarking the times when two Comets have deſcribed the ſame orbit. The only method, therefore, to perfect the aſtronomy of Comets is, to determine the trajectory of every one that appears, on the ſuppoſition of it's being a parabola; for ſuch a trajectory will always agree with the obſervations very nearly, as is evident from the great number of Comets whoſe trajectories have been thus ſettled. Then, when a Comet appears, if it be found to deſcribe the ſame trajectory as ſome Comet has formerly done, that is, one whoſe nodes are in the ſame place; whoſe plane has the ſame inclination to the ecliptic; and which has it's perihelion in the ſame place and at the ſame diſtance from the Sun;----it may be concluded, that theſe are two appearances of one and the ſame Comet. And the concluſion will be the ſtronger, if it be found that ſeveral Comets, after equal intervals of time, have deſcribed the ſame trajectory; for then there will be no reaſon to doubt, that all theſe were one Comet revolving in the ſame orbit. The intervals between theſe appearances will be the periodic time of the Comet; from whence it's return may be predicted; and from whence alſo the longer axis of it's elliptic orbit may be found, by the help of that famous rule which KEPLER firſt diſcover'd to obtain in fact, and which Sir ISAAC NEWTON afterwards demonſtrated muſt neceſſarily obtain in the revolutions of the planets; viz. that the ſquares of their periodic times are proportional to the cubes of their mean diſtances from the Sun, or to the cubes of the longer axes of their orbits, which are double of thoſe mean diſtances.

IN this manner Dr. HALLEY firſt ſhewed, that the ſame Comet had, in all probability, made two or three appearances. For a Comet, which he himſelf obſerv'd in the year 1682, deſcribed an orbit that agreed very well with the orbit of the Comet obſerv'd by KEPLER in 1607. If theſe were one and the ſame, it revolves in the ſpace of about 75 years; and the longer axis of it's orbit will be found, by KEPLER's rule, to be about $17\frac{3}{4}$ times greater than that of the earth's orbit; and it's diſtance from the Sun in it's aphelion about 35 times greater than the earth's mean diſtance from the Sun. And that they were the ſame, is confirm'd from hence, that in the year 1531 a Comet deſcribed an orbit, whoſe elements agree well with thoſe of the other two; there being no conſiderable difference, excepting only in the periodical time; one interval being 75 years; the other, 76. But the inequality of the periods is not greater than what may be attributed to phyſical cauſes. For as the Comet moved ſlowly in it's aphelion, at which diſtance the Sun's regulating power is but weak, it's motion was liable to be much diſturbed by the attraction of other Comets; by which means it's periodic time might be conſiderably alter'd. The aſtronomers have found the motion of Saturn ſo much diſturbed by Jupiter when near him, that ſome of his periods, obſerv'd accurately within a century paſt have been above 13 days longer than others. And by a calculation from the theory of gravity, ſome of Saturn's periods may be a month longer than others †. How much greater irregularities of this ſort muſt our Comet be expoſed to, which in its aphelion runs off from the Sun almoſt four times as far as Saturn; where it's gravitation to the Sun is 16 times weaker; and whoſe velocity in it's aphelion is not the tenth part of Saturn's velocity? It is not therefore to be wonder'd at, if it's periodic time, and it's orbit too, were ſomewhat changed.

UPON the ſuppoſition that it was the ſame Comet which appeared theſe three ſeveral times, the ſagacious Doctor predicted †, that "it would appear again about the end of the "year 1758, or the beginning of the following year." This prediction we have now the ſatisfaction to ſee verified; the preſent Comet agreeing hitherto ſo well with the former, as to leave little room for doubt that they are the ſame. We may therefore, upon ſure grounds, expect that the reſt of the Comets will return too; tho' we are not able as yet to prefix the years of their returns *. As it is not certain, that any other Comet has appeared twice, ſince Comets have been duly obſerved, we may conclude that all the other Comets have longer periods than this; and conſequently run off to greater diſtances from the Sun. From the curvature of the path of that which appeared in 1680, Sir Isaac Newton collected that it's period muſt be above 500 years; which will make it's greateſt diſtance from the Sun to be above 126 times greater than the earth's. And this, by the way, ſhews the vaſt extent of the power of gravity; for it muſt extend to the utmoſt diſtance to which any Comets riſe from the Sun;---in order to turn them round their aphelia, and bring them back in their orbits, as it does the Planets. To cloſe the preſent article: A theory, which ſo accurately anſwers to the motions of all the Comets which have been accurately obſerv'd, even to ſome which have been very extraordinary †, and which accounts for them by the ſame laws as the motions of the Planets are accounted for, cannot but be true.

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† Halleii Tab. Aſtron.

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* See the Appendix. † See the inſtances of the Comets in 1664 and 1680, in Newt. Princip. p. 505 and 522.

SINCE Comets move in the planetary regions, we may argue that they ſhine by reflecting the Sun's light ;---another circumſtance, in which they reſemble the planets. Accordingly, the brightneſs of their heads has been obſerv'd to increaſe as they have approached to the Sun, and to decreaſe as they have departed from him; altho' they have been going farther from the earth in the former caſe, and in the latter, coming towards it. Which ſhews that their brightneſs depends, not on their nearneſs to the earth, as their apparent magnitude does; but on their nearneſs to the Sun. And that Comets ſhine only by the light of the Sun, is manifeſt from an obſervation of HEVELIUS, that ſome * have caſt ſhadows behind them. Their ſhining only by the Sun's light ſupplies us with a reaſon why they are moſt frequently ſeen near the Sun, or in that hemiſphere of the heavens, in the middle of which the Sun is placed. For in their deſcent to the planetary regions, they are not ſufficiently illuminated by the Sun to diſcover themſelves, till they come within the ſphere of Jupiter †. Now the greater part of this ſphere is on that ſide of the earth, which looks toward the Sun, and therefore more Comets may be expected on that ſide than on the other.

YOU have now ſeen in what reſpects the Comets may be ſaid to be a kind of Planets. There

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* As that of 1665, whoſe ſhadow made a kind of fiſſure in the tail. Hevelii Cometogr. Lib. XII. p. 898.

† p. 12.

There is a conformity between them in theſe particulars: Both of them are compact, permanent, opake bodies; both ſhine, not by native light, as meteors do, but by reflecting the ſun's light; and both revolve in conic ſections round the ſun placed in one focus of their orbits, which, in all probability, are of the ſame kind, elliptic. But in other circumſtances there is a difference. Their orbits, tho' elliptic, are vaſtly more eccentric or oblong than thoſe of the Planets; the former being almoſt parabolic; the latter, almoſt circular. There is a difference, as well in the ſituation as in the figure of their orbits. The planes of all the planetary orbits are almoſt coincident with the ecliptic; that which differs moſt, making with it an angle of but 7°. But the orbits of Comets are inclined to the ecliptic in very different angles, ſome of them being almoſt perpendicular to it. The diſpoſition of their orbits is indeed as various as poſſible in every reſpect; as any one will ſee, that looks into Dr. HALLEY's table of them. Again: The real motion of all the Planets round the Sun is conſtantly direct; whereas the real motion of many Comets † is retrograde, or contrary to that of the Planets, as was intimated before *. This diverſity in the *real* poſition of their planes, and in the *real* direction of their motions, occaſions that great difference in their *apparent* courſes, which we took notice of, under the head of their general phænomena ‡. Such a variety in the direction of theſe motions is, by the way, a full proof, that there are neither ſolid orbs in the heavens, as ſome of the antients imagined; nor ſuch whirlpools of fluid matter, as many of the moderns have introduced, in order to account for the planetary revolutions.

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† About one half of the known Comets are retrograde.

* P. 12. ‡ P. 7.

BUT Comets ſeem to differ from the Planets in nothing more, than in that particular conſtitution of their bodies, or atmoſpheres, or both, which diſpoſes them to have tails;----an appendage, not in the leaſt degree belonging to any of the Planets. You have already ſeen the inſufficiency of ſome hypotheſes which had been propoſed to account for this appearance; and that the cauſe of it muſt be ſome extremely rare vapor reflecting the Sun's light. That the tail conſiſts of ſome matter derived from the nucleus, may be argued from hence, that Comets have the greateſt and brighteſt tails, quickly after they have paſs'd by the Sun; and thoſe have the longeſt tails, which go neareſt to him. By this it appears, that the heat, which the Comet acquires from the Sun, tends to increaſe the tail. Thus, the Comet of 1680, when it was firſt diſcover'd in its deſcent to the Sun, had no tail; after ſome days, a ſmall one aroſe, which increaſed in the approach to the Sun; but ſoon after the Comet had paſs'd it's perihelion, which was not a ſixth part of the Sun's diameter diſtant from the Sun, where it contracted a prodigious degree of heat *, it emitted

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* See above, p. 13.

mitted a very ſplendid tail of a ſurpriſing magnitude, extending in length above 70° ; which, conſidering it's diſtance from the earth, fell little ſhort of a hundred million miles. But this afterwards gradually diminiſh'd, untill it totally diſappeared. From hence it may be collected, that the tail is nothing but an extremely thin vapor, excited by heat from the nucleus of the Comet. Which is farther confirmed by a rule our great Philoſopher has given †, to determin at what time the vapor in the end of the tail began to aſcend from the nucleus ; by which rule he found, that almoſt all the vapor, which compoſed the tail of this Comet after it had paſs'd its perihelion, aroſe at, and ſoon after the time of the perihelion, when it ſuſtained the greateſt heat.

The tail of a Comet, being a vapor excited by the heat of the Sun, muſt conſiſt of matter of a texture different from what is in the Planets. For ſome Comets have never come ſo near to the Sun, as the earth always is ; many have not been nearer to him than Venus or Mercury, and ſo have never been expoſed to a greater heat than theſe Planets continually are ; yet have all theſe Comets ſent forth conſiderable tails. Which ſhews that the matter of theſe tails was of ſuch a peculiar texture as diſpoſed it to be eaſily rarefied, without a great degree of heat. Since the atmoſpheres of Comets are vaſtly larger in proportion to their bodies, than thoſe of the Planets are, ſo far as we can judge of the other Planets, by analogy, from our own; and ſince they abound much more with vapors, as is evident from their thick and turbid appearance; they ſeem to be a proper fund, to ſupply matter in ſufficient plenty for the formation of the tails. For tho' ſome of theſe tails are vaſtly long, yet they are ſo thin, that an inconſiderable quantity of matter, duly rarefied, may ſuffice to produce them. We find, that a very little feuel will make ſmoke enough to fill a very large ſpace.

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† Newt. Princip. p. 513.

The aſcent of the tails in a direction oppoſite to the Sun, our illuſtrious author thinks owing to the rarefaction of the matter of which they conſiſt. For as in our atmoſphere, where every thing gravitates to the earth, the ſmoke of any body mounts upward from the earth; and that either perpendicularly, if the body be at reſt; or obliquely, if that be moved ſideways: So in the heavens, where all things gravitate to the Sun, ſmoke and vapors ought to aſcend from the Sun; either right upward, if the fuming body were at reſt; or obliquely, when that, by being in motion, leaves the places from which the ſuperior parts of the vapor had aſcended. "The air in a chimney, ſays Sir Isaac †, being rarefied by heat, becomes ſpecifically lighter than the neighbouring air, and therefore neceſſarily riſes in it, and carries up the ſmoke with it; and thus the vapor in the tail of a Comet being warm'd, will warm the æthereal aura or ſolar atmoſphere, wherein it is involved; which by this warmth being rarefied, and it's ſpecific gravity towards the Sun diminiſhed, it will aſcend, and carry with it the matter which makes the tail;" and this matter, by it's rarefaction, will continually expand on all ſides, and make the upper end of the tail the broadeſt and thinneſt. The æthereal aura muſt be ſuppoſed extremely rare and next to a vacuum, at the diſtance at which ſome Comets paſs from the Sun; yet, be it ever ſo rare, if that part of it, which is involved within the atmoſphere and tail of a Comet, be made rarer by heat than the ambient parts are, it muſt riſe in them, by the known laws of ſpecific gravity.

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† Princip. p. 514.

From what has been ſaid it appears, that the vapor, which makes the tail, has a compound motion;---a motion of aſcent right upward from the Sun, and a progreſſive motion, which it had in common with the nucleus. All the parts of it muſt therefore, by their gravity toward the Sun, revolve round him in conic ſections, for the ſame reaſon as the nucleus itſelf does; and, tho' detach'd from that, will accompany it in it's progreſs, till by ſlow degrees they are diſſipated. Here you may ſee the reaſon, why the tail is often a little incurvated, and ſometimes bifurcated; and why it is not turned exactly to the point oppoſite to the Sun. To keep the tail ſtrait, and exactly turned from the Sun, all the parts of it ſhould deſcribe greater arcs in the ſame time, and therefore move with greater velocities than the nucleus ;--- greater, in the ſame proportion as they are more diſtant from the Sun. But the progreſſive motion, which they receive from the nucleus, can never give them a greater velocity than that has. Therefore the upper parts will be left a little behind, or on that ſide from which the Comet is moving ; and the tail will be bent, with it's convexity on that ſide toward which theComet is moving. Farther : As the orbit of a Comet is very curve near the perihelion, thoſe vapors, which make a tail before the perihelion, riſe in a different direction from thoſe after the perihelion. The conſequence of this may be a forked tail ; being, as it were, two tails, joined together near the nucleus, and divaricating toward their upper ends.

The tail, being always nearly oppoſite to the Sun, will follow the head of the Comet, while that is deſcending to it's perihelion ; and will precede it, in its aſcent. And if the Comet be near a ſtrait line paſſing thro' the Sun and the earth, and ſo be near it's conjunction or oppoſition with the Sun ; the upper end of the tail being broadeſt, will appear to ſurround the head of the Comet on all ſides, like hair.

Thus have we endeavour'd to explain the general phænomena of Comets, enumerated in the beginning of the forgoing diſcourſe. Concerning their uſes and effects, two or three things are now to be ſaid.

It is not to be doubted, that the alwiſe Author of nature deſigned ſo remarkable a ſort of bodies for important purpoſes, both *natural* and *moral*, in His creation. The *moral* purpoſes ſeem not very difficult to be found. Such grand and unuſual appearances tend to rouſe mankind, who are apt to *fall aſleep*, while *all things continue as they were*;---- to awaken their attention, and to direct it to the ſupreme Governor of the univerſe; whom they would be in danger of totally forgetting, were nature always to glide along with an uniform tenor. Theſe *exotic* ſtars ſerve to raiſe in our minds moſt ſublime conceptions of GOD, and particularly diſplay his exquiſite ſkill. The motions of many Comets being contrary to thoſe of the Planets, ſhew that neither of them procede from neceſſity or fate, but from choice and deſign. The ſame thing is to be ſeen in the figure and ſituation of their orbits; which indeed have not the appearance of regularity, as thoſe of the Planets, and yet are the reſult of admirable contrivance. By means of their great eccentricity, they run ſo ſwiftly thro' the planetary regions, as to have but very little time to diſturb their own motions, or thoſe of the Planets. And this end is ſtill more effectually anſwered in thoſe Comets whoſe motion is retrograde, or contrary to that of the Planets. In this caſe, the *relative* velocity wherewith the Comet and Planet run by each other is the *ſum*; but when Comets move the ſame way as the Planets, 'tis the *difference*, of their real velocities*. By this great eccentricity likewiſe, as well as by the very different ſituation of their planes, they are at vaſt diſtances from each other in their aphelia; where their motions are ſo ſlow, and their gravitation to the Sun ſo weak, that their mutual gravitation might produce irregularities, and perhaps throw the ſyſtem into confuſion; which this precaution has guarded againſt.

BUT without inlarging on theſe things, I muſt haſten to ſpeak a little of the *natural* purpoſes, to which Comets may be ſubſervient. To aſſign all theſe in particular, may perhaps never be in the power of mortals; to be ſure, it is not to be expected at preſent, while our knowledge of the cometic ſyſtem is but in it's dawn. It does not ſeem very likely, that they ſhould be intended, as the Planets, to afford an habitation for animals. The very great eccentricity of their orbits expoſes them to ſuch mighty changes of light and darkneſs, of heat and cold, as ſeem to imply that they are deſigned for purpoſes very different from the Planets. If the Comet of 1680 revolves in 575 years, as ſome have ſuppoſed (and it's period cannot be much ſhorter than this *; tho' it may be much longer) it's greateſt diſtance from the Sun muſt be above 23,000 Times greater than it's leaſt diſtance; and the light and heat of the Sun being every where reciprocally as the ſquares of the diſtances, the Comet's greateſt light and heat is above five hundred million times greater than it's leaſt. Extremes like theſe muſt, one would think, deſtroy all vegetables and animals, in the leaſt degree reſembling thoſe we are acquainted with. And yet, ſuch is the inexhauſtible variety of the works of GOD, that it is more than poſſible, that there may be vegetables and animals, to which ſuch extremes may be as neceſſary as thoſe, to which our globe is ſubject, are to ours. However, it ſeems moſt probable, that the Comets are deſigned to be ſome way or other ſerviceable to the planetary worlds. Thoſe who ſee with unphiloſophic eyes are, I ſuppoſe, generally alarm'd at the ſight of a Comet; and indeed the bulk of mankind ſeem diſpoſed, by a ſort of natural ſuperſtition, to turn every unuſual phænomenon into a preſage of ſome dire event. Of the truth of this obſervation, ſo far as it relates to Comets, the hiſtories of them afford an inconteſtable proof. But theſe

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* The velocity of a Comet is to that of a Planet, at the ſame diſtance from the Sun, nearly as 7 to 5. Therefore the *relative* velocity of retrograde Comets is to that of direct ones as 7+5 to 7—5, that is, as 12 to 2. So that a retrograde Comet in its tranſit by a Planet will continue within a given diſtance from it, but one ſixth part of the time that it would, if it were direct. This would be ſtrictly ſo, in caſe a Comet and Planet ſhould paſs by each other in parallel directions. But the greater the deviation from paralleliſm is, ſo much the leſs difference will be made, in the time of their continuing near one another, by a Comet's being retrograde or direct.

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* See above, p. 30.

theſe objects of terror may be productive of great advantages. 'Tis the judgment of Sir ISAAC NEWTON *, that the tails of Comets may be intended to recruit the perpetual waſte of fluids in the Planets by vegetation and putrefaction. The tails ſometimes reach to an immenſe diſtance †; and the rarefied vapor, dilating itſelf toward their upper end, muſt gradually be diffuſed throughout the heavens, and by it's gravity be drawn into the atmoſpheres of the Planets, and mingle with them. He farther ſuſpects, that the moſt ſubtle and ſpirituous part of our air, which is moſt requiſite to maintain life, may come principally from the Comets. Another end of them may be, to ſupply the perpetual conſumption of the Sun ‡. TheComet of 1680 deſcended ſo near to the Sun †, that it probably enter'd, and that with an exceſſive velocity, into the denſer part of his atmoſphere, where meeting with a ſenſible reſiſtence, it might be a little retarded; and if ſo, in it's next revolution it will go nearer the Sun, and be more retarded; and being thus retarded in every revolution, it muſt at length fall upon the Sun, and may ſerve for new feuel to feed his flame. It may be more retarded by the attraction of other Comets in it's aphelion, where it's motion is very ſlow; and by that means may the ſooner fall into theSun. Such may probably be ſome of the uſes of Comets; and as our knowlege of their number, their periods, and the figure

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* Princip. p. 515. † See above, p. 33, 34. ‡ Princip. p. 525.

and ſituation of their orbits advances, more may be diſcovered.

ON the other ſide, it ought not to be concealed, that they ſeem fitted to be the miniſters of divine juſtice as well as goodneſs, and capable of producing very great and deſtructive changes in the planetary worlds; ſome of them having their nodes ſituated not far from the orbits of the Planets. Were a Comet to paſs very near a Planet, it would increaſe the tides in the ocean (if the other Planets have oceans as well as our earth) and might ſwell them ſo as to drown the lower countries, if not the mountains; and ſhould the Planet at the ſame time paſs thro' the tail of the Comet, the vapors of that, ſuppoſing them to be aqueous, might, by turning into rain, greatly increaſe the inundation. By ſuch a near approach of a Comet to the earth, has the ingenious and learned Mr. WHISTON endeavour'd to account for the univerſal deluge ſpoken of in the holy ſcriptures. And if he has not ſatisfactorily accounted for every particular upon this hypotheſis, at leaſt he has produced much more evidence of various kinds than could have been expected in a matter of ſuch early antiquity, to prove that, in fact, a Comet came very near and paſs'd by the earth, on the day the deluge began; and if ſo, it could not but have a very great influence in bringing on that moſt aſtoniſhing cataſtrophe. Indeed, according to the laws of nature, particularly thoſe of gravity, it is not poſſible but that the near approach of a

Comet to a Planet, either in it's deſcent to the Sun or aſcent from him, ſhould draw after it a train of dangerous, if not fatal conſequences. Several of theſe might eaſily be mention'd; and many others there may be, of which we have not at preſent the leaſt ſuſpicion.

But inſtead of entring here into a detail, which would probably anſwer no valuable end, I chooſe rather to turn your thoughts to that conſummate Wisdom, which preſides over this vaſt machine of nature, and has ſo regulated the ſeveral movements in it, as to obviate the damage that might ariſe from this quarter. None but an eye able to pierce into the remoteſt futurity, and to foreſee, throughout all ages, all the ſituations which this numerous claſs of bodies would have towards the Planets, in conſequence of the laws of their reſpective motions, could have given ſo juſt an arrangement to their ſeveral orbits, and aſſigned them their places at firſt on their orbits with ſuch perfect accuracy, that their motions have ever ſince continued without interfering, and no diſaſters of this ſort have taken place; unleſs we except the caſe of the deluge. For tho' ſo many Comets have traverſed this planetary ſyſtem, and ſome of their orbits run near to thoſe of the Planets; yet the Planets have never been in the way †, but always at a diſtance from the neareſt point, when the Comets have paſſed by it.

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† The Comet of 1618 came to its deſcending node, the 19th of *September*. Dr. Halley obſerves, that if it had come to

it. The foreſight of that great Being, which has hitherto prevented ſuch diſorders, will continue to prevent them, *ſo* long as HE ſees it fit the preſent frame of nature ſhould ſubſiſt. Longer than that, it is not fit that it ſhould ſubſiſt.

It may not be unſeaſonable to remark, for a concluſion, that as, on the one hand, it argues a temerity unworthy a philoſophic mind, to explode every apprehenſion of danger from Comets, as if it were impoſſible that any damage could ever be occaſioned by any of them; becauſe ſome idle and ſuperſtitious fancies have in times of ignorance prevail'd concerning them: So on the other, to be thrown into a panic, whenever a Comet appears, on account of the ill effects which ſome few of theſe bodies might poſſibly produce, if they were not under a proper direction, betrays a weakneſs equally unbecoming a reaſonable being. The wiſeſt courſe is, to aim at ſuch a rectitude of intention and firmneſs of reſolution, that, as Horace ſays,

Si fractus illabatur orbis,
Impavidum ferient ruinæ.

Read, 18th of April, 1759.

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it about the middle of *March* [I think he ſhould have ſaid *May*] it would have paſs'd within $\frac{1}{20}$ of the Sun's diſtance from the earth. And ſo would the Comet of 1686, had it arrived at it's aſcending node a little ſooner. But no Comet has threaten'd the earth with a nearer approach than that of 1680; which, had it come down to the Sun a month later, would have paſs'd as near the earth as the moon is.

APPENDIX.

APPENDIX.

Concerning the Revolutions of the preſent Comet, and of ſome others.

THIS year, 1759, has done great honor to aſtronomy. It has added a new confirmation to Sir ISAAC NEWTON's theory of Comets, which was indeed very well eſtabliſhed before; and it has verified the firſt prediction that ever was made of the appearance of a Comet;--- the firſt, I mean, that ever was made upon aſtronomical principles: For aſtrological or enthuſiaſtical predictions of theſe or any other unuſual phænomena deſerve no regard, but are to be treated as the dreams of viſionaries. And yet, trifling and contemptible as they are, ſuch have been made both in former and later times *. This firſt aſtronomical prediction was made by Dr. HALLEY, in perſuance of the theory now mention'd; and the grounds, upon

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* Halley's Synopſ. Aſtron. Comet.

upon which he went in making it, have been laid open in the foregoing papers, p. 28. They were in brief: That the Comets, which appear'd in the years 1531, 1607 and 1682 deſcribed trajectories in the heavens, the obſerv'd part of which was ſenſibly parabolic; and upon computation, their trajectories were found to be nearly the ſame. The inference from which, according to the principles of this theory, is, that theſe were one and the ſame Comet, revolving in a very long elliptic orbit, in about 75 or 76 years. From hence the Dr. predicted, that "it would return in the year 1758;" as he firſt publiſhed in 1705 †. Having afterward look'd over the catalogues of more antient Comets, and diſcovered that three others had preceded the aforeſaid three, in like intervals of time, viz. in the years 1305, 1380 and 1456, he was more confirm'd in his opinion that they were the ſame Comet. But having remark'd the inequality of it's periods, that ſome were under 75 years, and others above 76, and conſidered the effect which the action of Jupiter upon the Comet, by the force of gravity, might probably have had, about the time of it's laſt appearance in 1682, he concluded, that "it would not return till af-"ter the longer period of above 76 years, about "the end of the year 1758, or the beginning "of the next*." With what ſagacity and accuracy of judgment this concluſion was drawn, the event has ſufficiently declared. At the ſame time he expreſſed his confidence, that "if "it ſhould return again at the time he had "foretold, impartial poſterity would not re"fuſe to acknowledge that this was firſt diſ"cover'd by an *Engliſhman.*" It is to be hoped, the preſent age will not forfeit the character of impartiality; but that all the world will now unite in doing juſtice to ſuch diſtinguiſhing merit.

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† Phil. Tranſ. No. 297.

* Synopſ. Aſtron. Comet.

As this Comet is on ſome accounts more remarkable than the reſt, I perſuade my ſelf a ſhort *Hiſtory* of it will not be unacceptable to the curious. I ſhall therefore throw together the principal things that I have met with concerning it.

It's firſt appearance, that may be depended on, is that in 1305. As to which, all we find is, that it was ſeen about Eaſter, that is, in April, as it was this preſent year; and that it was, † according to the language of thoſe days, "of "a horrible bigneſs": Tho' 'tis likely it did not appear bigger at that time, than it did on the 29th of April laſt. For it could hardly ever have been ſeen much nearer to the earth, than it was this laſt time. It is to little purpoſe to look for any appearances of it prior to this. For tho' I find in Hevelius's and Lubienietski's Hiſtories of Comets mention of the appearance of Comets about ſome of thoſe times when, it is probable, this appeared, as within a year or two before and after; yet there is no way to determin which of theſe was the ſame as the preſent Comet.

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† Horrendæ magnitudinis. Lubienietſki Hiſtoria omnium Cometarum, p. 251, 2.

It's next appearance was in 1380; but the time of the year is not mention'd. All the Account is, ‡ that "a burning Comet appeared "in Aquarius for three months together." From it's appearing for ſo long time in Aquarius, we may conclude that it was in the winter; probably in the beginning of that year.

It appeared a third time in 1456. The ſum of the accounts then given of it are †, that "a "Comet of an unheard-of bigneſs was ſeen "toward the eaſt in the middle of Cancer, the "whole month of June, with a tail of ſuch a "length as to reach almoſt two ſigns." By this it ſeems, the tail was much longer than it has been ſeen at any other time. But it is to be obſerved, that the Comet was then near it's perihelion, where the tail is always largeſt; and the earth was in ſuch a poſition as to view the tail almoſt directly, and therefore under the largeſt angle that can be. However, nothing is more likely than that the matter is exaggerated; moſt of the old deſcriptions of Comets being drawn up in very ſtrong terms. Of which we have a ſignal inſtance in this very quotation, wherein the Comet is ſaid to have been "of an unheard-of bigneſs". For theſe words refer to the body, and not to the tail of the Comet; as is plain in the original †, "Cometa inauditæ magnitudinis apparuit, cum "prælonga cauda". Now the bigneſs of it's body could ſcarcely deſerve ſuch an epithet; as we juſt obſerv'd, under it's firſt appearance. Whether the ſame Comet may emit a longer tail in ſome revolutions than others, is a matter which, I ſuppoſe, has never been inquired into.

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‡ Lubien. p. 270.

† Lubien. p. 292.

HITHERTO the accounts are very defective; and we can learn nothing from them, of the Comet's courſe in the heavens.

BUT the next time it was ſeen, which was in 1531, it's courſe was obſerved, tho' imperfectly, by APIAN, one of the moſt learned aſtronomers of thoſe days, but furniſh'd with very indifferent inſtruments. He it was who diſcovered †, that the tails of Comets are turned from the Sun; and made only ſuch obſervations on this Comet, as ſerved to eſtabliſh that diſcovery. It is ſaid * to have been "ſeen "from the 6th of Auguſt, till the 3d of September, in the N. W. at firſt in the morning before ſun riſe, and afterwards in the "evening after ſun ſet. It went thro' Leo, "Virgo and Libra; going ſometimes 4° in a "day, ſometimes 5°, and ſometimes 6°. It "had north latitude, which was daily decreaſing." Tis alſo ſaid ‡, that it was a bearded

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† Hevel. Cometogr. Lib. VIII. p. 461. * Lubien. p. 33.
‡ Hevel. Lib. XII. p. 846.

"ſtar, of a reddiſh or rather yellow color." From APIAN's obſervations of it's courſe, Dr. HALLEY computed it's parabolic trajectory; ---that it's proper motion in it was retrograde; tho' it's apparent motion was direct;--and that it was in perihelion, Auguſt 25.

IT's fifth appearance was in 1607, when it's courſe was obſerv'd by the famous KEPLER with greater care than it had been before. The ſubſtance of the accounts, as we find them in HEVELIUS † and LUBIENIETSKI *, are, "that it was ſeen 41 days from the 16th "of September; at firſt in the evening, and "afterwards all night; ---that it had a very "ſmall parallax, and ſo was no ſublunary va-"por, but elevated to a great hight in the æ-"ther;---that it proceded with a direct mo-"tion thro' Libra, Scorpio and Sagittarius; "at the end of September very ſwiftly, not "leſs than 13° in a day, but more ſlowly before "and after; and near the time of it's diſap-"pearing, being almoſt ſtationary; --- that it's "face was ſpotted and not round;--- that it "was larger than all the fix'd ſtars, and al-"moſt as large as Jupiter himſelf;---that it's "light was weak, pale and watery, like that "of the moon, when near the ſhadow of the "earth;---that toward the end of it's appear-"ance, it's head was more and more di-"miniſhed;---that it's tail was about 7° long, "and projected oppoſite to the Sun, tho' with

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† p. 871. * p. 407.

"ſome deviation"; and laſtly, that, agreable to the terrific manner of deſcribing Comets, which was not yet laid aſide, "it appear'd like "a fiery ſpear or flaming ſword." From it's apparent courſe, which KEPLER had particularly deſcribed for every night in which he obſerv'd it, Dr. HALLEY determin'd it's trajectory; fixing the time of the perihelion to October 16.

IT's ſixth appearance was in the year 1682, when it's motion was obſerv'd with all poſſible exactneſs by the beſt aſtronomers in the world, and with the beſt inſtruments; teleſcopes having been then applied to the making aſtronomical obſervations. It was ſeen from the 15th of Auguſt to the 9th of September; at firſt in the morning, afterwards in the evening. It's apparent motion was all the while direct, thro' Leo, Virgo and Libra. In the beginning it was accelerated, 'till it became almoſt 6° in a day; after that, it was retarded, till towards the end it was not more than 2° in a day †. It had north latitude, which at firſt increaſed till it was above 26°, and then decreaſed to leſs than 9°. It's head was brighter and ſomewhat larger than the famous one of the year 1680, but it's tail not near ſo long. By Mr. FLAMSTEED's obſervations at the Royal Obſervatory in *Greenwich*, the nucleus was hardly a tenth part ſo broad as the atmoſphere ſurrounding it; which being meaſured by a micrometer was 2' ; and therefore the nucleus was only 11'' or 12'' in diameter*. HEVELIUS found it's tail, when longeſt, to be about 15° or 16° ; but toward the end it daily diminiſhed ; and it deviated from the preciſe point of oppoſition to the Sun. By Dr. HALLEY's computation of it's trajectory, it came to it's perihelion September 4th.

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† Lowthorp's Abridg. Phil. Tranſ. Vol. I. p. 447.

OF it's ſeventh appearance we our ſelves are eye-witneſſes. It was firſt ſeen, in this part of the world, on the 3d of April in the morning ; but might have been ſeen much ſooner, had not an uninterrupted ſucceſſion of cloudy weather prevented it. On the 4th, at $3\frac{3}{4}$ h, I ſaw it, low in the eaſt and not very bright, with a tail about 3° or 4° long, directed obliquely upward, toward the S. W. It was then in about 26° of Aquarius, with 4° of north latitude. From hence it went weſterly, or with a retrograde motion ; and ſoutherly withal, approaching toward the ecliptic, which it croſs'd on the 11th. At firſt it mov'd not above half a degree in a day ; but with a motion greatly accelerated, by reaſon of it's coming almoſt directly towards the earth, it paſs'd from the middle of the back of Aquarius, over the tail of Capricorn, and ran ſo far ſouthward by the 22d, as not to riſe above our horizon. While it was inviſible to us, it might be ſeen in the ſouthern countries, going over the tail of Pavo, and ſouth of Triangulum Auſtrale, and thro' the Croſiers, within 20° of the ſouth pole of the equator. After it had paſs'd it's neareſt diſtance from the ſouth pole, the direction of it's apparent motion muſt of neceſſity become northerly; by which means, it roſe again above our horizon on the 27th. The laſt time I ſaw it before it left us, on it's ſouthern progreſs, was on the 19th in the morning; and the firſt time after it's return, on the 29th, in the evening; when it appeared bigger than before, tho' not ſo bright, but rather of a dull and gloomy aſpect; and it's tail was longer and broader, ſeeming to be about 7° long and directed toward the eaſt. Theſe alterations were owing to it's being nearer to the earth, and farther from the Sun *. It's apparent courſe was now N. W. toward that part of Hydra, which is under Crater; and it croſs'd Hydra in about 15° of Virgo. As it was now going farther both from the earth and the ſun, it's motion became ſlower, and it's bigneſs and brightneſs were continually diminiſhing. The laſt time I ſaw it, before the writing of this, was on the 22d of May in the evening, when at 9 h ¼, I found it on the limb of Sextans Uraniæ, in about 8° of Virgo, and 14° of ſouth latitude; with ſome uncertainty, ariſing from the faint appearance it made; which will increaſe ſo as, in a little time, will make it difficult to find the Comet, eſpecially when the moon-light nights come on. It's diurnal motion is now ſcarcely one quarter of a degree.

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* Newt. Princip. p. 481.

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* See above, P. 31.

degree. It's apparent motion has all this while been retrograde, as well as it's real motion; whereas in it's former returns, it's apparent motion was direct. This difference is occaſioned by the earth's being now on the north ſide of the Comet's orbit; whereas before, it happened to be always on the ſouth ſide. But the calculations made on the orbit of 1682 agree as well with the laſt obſervations we have made of the Comet, as they did with the firſt; and this agreement proves, both that it was the ſameComet which appeared the beginning of April in the morning, and the end of April in the evening; and that this is the ſame Comet as that of 1682.

Such has been it's courſe as ſeen from the earth. If the Reader be deſirous to know the principal *ſtages* of it's preſent journey, they are as follow. In December 1720, it was in it's aphelion, or greateſt diſtance from the Sun;--- of above 28 hundred million miles. From that time it approach'd the Sun; very ſlowly at firſt,but with a motion continually accelerated. Two years and an half ago, it enter'd the ſphere of Saturn; that is, came as near to the Sun as Saturn is; and the beginning of March 1758, it enter'd the ſphere of Jupiter. It was in it's aſcending node about the middle of December laſt; being then beyond the ſphere of Mars, which it enter'd on the laſt of that month; as it did the ſphere of the earth on the firſt of February. Poſſibly, in the beginning of

January and for ſome time after, it might have been ſeen in the weſtern hemiſphere in the evening, at firſt not far from the point of the vernal equinox, and then to the weſt of it; if one had known exactly where to look for it. At that time it was as near the Sun as it was on the 22d of May, but not ſo near the earth; and therefore not bright enough to make people in general take notice of it. On the 10th of February, it was got to that point of it's orbit where KEPLER firſt ſaw it on the 16th of September 1607; which is the moſt eaſtern point that we have any account of it's having been ſeen in; as that on the 22d of May inſt. is the moſt weſtern. On the 20th of February it enter'd the ſphere of Venus; but never went ſo low as that of Mercury. On the laſt of February, it was in conjunction with the Sun, with but little more than 6° north latitude; and was then hid in the ſun's rays. But by it's retrograde motion it ſoon got to the weſtward of the Sun, and came to it's perihelion March 12; it's diſtance from the Sun being then almoſt 47 million miles. It's geocentric place was then in 5° of Piſces, with a little above 6° north latitude, as before. At that time, or ſoon after, it might undoubtedly have been ſeen in the eaſt; for it roſe 1 h. 10′ before the Sun. On the firſt of April, it went out of the ſphere of Venus; on the 11th, paſs'd it's deſcending node; and left the ſphere of the earth, on the 20th. It came to it's perigee or neareſt diſtance from the earth, on the 25th;

which was about ten million miles. It was in oppoſition to the Sun, the 26th, having about 50° ſouth latitude. At this time it's diurnal motion was about 17°. It left the ſphere of Mars the 23d of May; and will leave that of Jupiter about the middle of next March, and that of Saturn in September 1761; continuing it's courſe thro' the ſouthern parts of the heavens till the year 1834, when another viſit may be expected from it.

To compare it's different periods, it will be beſt to place in one view it's ſeveral appearances, and the times of it's perihelion, ſo far as we know them.

	Years.	Months.	Periods.
1.	1305,	April,	
2.	1380,	about Jan. probably,	74 Years, and about 10 months.
3.	1456,	June,	76 —— and about 5 months.
4.	1531,	Auguſt 25.	75 —— and two months.
5.	1607,	October 16.	76 —— and 52 days.
6.	1682,	September 4.	74 —— and 323 days.
7.	1759,	March 12. N.S.	76 —— and 178 days.

Upon this view it is obvious, that the periods of the Comet have been alternately greater and leſs; tho' the three firſt cannot be exactly determined. The laſt ſeems to have been as long; and the laſt but one, as ſhort as any; the difference between them being a year and 220 days. This ſeems a great difference when compared with the ſmall irregularities which the revolutions of the Planets are ſubject to †; but perhaps, when we know more of Comets, it may appear inconſiderable.

To find the mean revolution, [illegible]nnot come to any greater exactneſs, than [illegible] ſuppoſing that in 1305 it was in it's perihelion at the ſame time of the year as it was this year; for both times it appeared in April. Therefore in 454 years it has made 6 revolutions; which gives $75\frac{2}{3}$ years for a mean revolution. Whence, ſuppoſing the earth's diſtance from the ſun to be of 100 parts, we find, by KEPLER's rule *, the longer axis of the Comet's orbit to be 3578 of thoſe parts; and it's perihelion-diſtance being 58, it's aphelion-diſtance is 3550. Thus, the Comet's leaſt diſtance from the Sun is to it's greateſt as 1 to above 60. In the perihelion, the Sun's diameter would appear to the Comet almoſt double of what it does to us; but in the aphelion, the Sun would not look bigger than Jupiter and Venus in perigee do to us. And the Sun's light and heat being reciprocally as the ſquares of the diſtances, the light and heat at the Comet in it's perihelion is above 3600 times greater than it is at the aphelion. The Comet's angular velocities are alſo in the ſame proportion. In it's aphelion it moves but 18' of a degree in a year: whereas in it's perihelion it runs thro' an equal angle in 2 h 24.' It continues on the north ſide of the ecliptic, where it's perihelion lies, but

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† See above, P. 29.

* Page 28.

114 days; and ſpends on the ſouth ſide all the reſt of it's long revolution.

A[illegible] real bigneſs of the nucleus---Mr. FLAMS[illegible] in 1682 found it but 11'' or 12'' in diame[illegible], as was remarked before, p. viii. which is very nigh the bigneſs that Mercury appears of in his tranſits over the Sun at his aſcending node: And the Comet's diſtance from the earth at that time could not differ much from the Planet's. Therefore the Comet may well be ſuppoſed to be about the ſame bigneſs as the planet Mercury, which is the leaſt of all the Planets, and but $\frac{1}{27}$th part ſo big as the earth. If we could find on what day Mr. FLAMSTEED made his obſervation, we might determin this point with greater exactneſs.

THE tail was of an enormous length, by the account given of it in 1456. But the later accounts are probably exacter; of which the moſt diſtinct I can find is that of HEVELIUS before cited *, who in 1682 found it about 15° or 16° long. According to this, it's real length was almoſt 12 million miles; which is long enough to reach from the deſcending node beyond the earth's orbit. So that if the Comet had come to that node about a month later, this year, or more exactly on the 14th of May, the earth would have paſs'd thro' the end of it's tail.

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* p. viii.

With regard to this Comet I ſhall only obſerve farther, that the aſcending node of it's orbit lies pretty near the orbit of Mars; and the deſcending, near that of Venus. After the aſcending node, it may poſſibly come within about 12 million miles of the earth; and after the deſcending within 5 million; as it would have done this year, had it come to it's deſcending node but 9 days later than it did. And theſe are the neareſt approaches which it can poſſibly make to the earth.

We have not the like evidence of the return of any other Comet, as we have of this. Dr. Halley was inclined to believe that the Comet of autumn 1532 deſcribed the ſame orbit with that which was obſerv'd by Hevelius in the beginning of the year 1661; and if ſo, it's period was of $128\frac{1}{4}$ years. [†] Tho' he remarks that Apian's obſervations, which are the only ones extant of the firſt, are not exact enough to decide with certainty ſo nice an affair. What makes it probable to me is, that on looking into the hiſtories, I find Comets appearing in thoſe years, which a period of about 128 or 129 years, reckon'd backward, falls upon. Lubienietski ſpeaks of one that was ſeen in the end of March and beginning of April 1403; which was $129\frac{1}{2}$ years before that of 1532, and might probably be the ſame. He ſpeaks of another in July and Auguſt, 1273, which was $129\frac{2}{3}$ years before the laſt mentioned;

[†] Phil. Tranſ. No. 297.

ed; and of another in May, 1145, which was $128\frac{1}{2}$ years before that; and of another, which appear'd for four months in 1017, or about 128 years before the laſt mention'd. But as I find none in the period next before this, it is needleſs to look farther back. The differences of theſe periods, being not greater than what we found in our preſent Comet, are no objection to all theſe Comets being the ſame; tho', as we have no account of their courſes, one cannot poſitively affirm that they were. If they were, it's mean period is $128\frac{4}{5}$ years; and it will return in the year 1789, or 1790.

So far as an argument might be drawn from an equality of periods and from ſimilar phænomena, * Dr. HALLEY thought that the period of that wonderful Comet of 1680 might be 575 years. Sir ISAAC NEWTON, from the curvature of it's path, judged it's period to be above 500 years †; and the learned Doctor, having found mention in hiſtory of four appearances of famous Comets, with remarkably long tails, after intervals of 575 years, was ready to conclude that theſe were the ſame Comet. The appearances were, in September after the death of JULIUS CÆSAR, 44 years before the Chriſtian æra; in the year 531, in the reign of the emperor JUSTINIAN; in February 1106, in the reign of our K. HENRY I; and in December 1680. The Doctor added "ſimilarity of phænomena"; being ſenſible, without

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* Synopſ. Aſtron. Comet.

† As above, P. 30.

without doubt, that the argument drawn from the equality of periods can, by itſelf, have no great force. For ſo frequent have been the appearances of Comets, that a number of imaginary periods might eaſily be aſſumed, which, reckon'd in order for three or four ſucceſſions, might fall on years wherein Comets were ſeen. 'Tis pity the Doctor could meet with no account of the courſes of theſe Comets in the heavens; which might have decided the queſtion with certainty on one ſide or the other. Since his death, a manuſcript has been found in the library of Pembroke-Hall in *Cambridge*, which gives ſome, tho' a very imperfect account of the courſe of that Comet which appeared in 1106. And the Author *, who mentions it, obſerves, that "there is ſuch a "wide difference between this manuſcript ac- "count and the Comet's places computed on "the orbit of 1680, as muſt very much leſ- "ſen, if it does not quite overbalance, the "force of the arguments brought by Dr. HALLEY to prove the identity of theſe two Co- "mets."

THIS manuſcript gives alſo a ſhort account of a famous Comet which was ſeen in 1264. So far as it's trajectory could be determin'd from that ſlender deſcription, there is found ſuch a reſemblance between it and that of the Comet of 1556, as gives ſome ground for conjecture that they might poſſibly be the ſame.

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* Mr. DUNTHORNE in Phil. Tranſ. Vol. xlvii. Art. xliii.

If they were, it's period is 292 years; and it may be expected about the year 1848.

This is the ſubſtance of what we have collected in regard to the revolutions of Comets. Our knowledge in this article is very imperfect; but we are now in the right way to have it inlarged. Every Comet that appears will either increaſe the number of Comets, or diſcover the period of ſome one that was unknown. As the number of Comets increaſes, it may be beſt to diſtinguiſh them by names. Hitherto, each has been known only by the year of it's appearance; as the Comet of 1680, or that of 1682, &c. But perhaps it may be more convenient to range them in numerical order, as the aſtronomers do the ſatellits of Jupiter and Saturn; reckoning thoſe firſt, whoſe periods are ſhorteſt. In conformity to which way of ſpeaking, our preſent Comet is doubtleſs the *firſt* Comet; and that of 1661 may probably be the *ſecond*. 'Tis natural to expect that the periods of others will be diſcovered in nearly this numerical order; for the ſhorteſt are likely to be diſcovered ſooneſt. But it will require the obſervations of many hundreds, if not thouſands of years, to complete the Cometic ſyſtem.

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THE END.